Living with a Star Measurement Requirements Workshop

Space Environments and Effects (SEE) Program

Billy Kauffman

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Ionizing Radiation: Current Environment Models & Data

- Typically Used by Radiation Community:
  - AP8, AE8, CREME96, NOAAPro, JPL Solar Proton, SOLPRO, NOVICE, MACREE, ESP
  - Spenvis: Free integrated environment tool online (ESA); used by commercial industry

- Other: NOAA Online Data
  - High energy data
  - Does not include models but data used for "now casting"
  - Good for operational decisions
  - Includes GOES and TIROS data sets

On-Going Efforts

- SEE Program
  - Trapped proton model developed by Boeing (collaboration with AFRL/Hanscom; update to AP8)
- Analyzing existing data sets to improve/update models
  - ESA analyzing SAMPEX data to improve trapped proton models
  - France is performing dynamic electron modeling to look at belt production (theoretical)
  - Japan, Russia, University of Vermont, University of Michigan
- Collaborations would prove useful

Gaps in Modeling

- AP8
  - Although an effort is underway, there is not enough resources in addressing current needs
  - Very little high energy and high altitude data
- AE8
  - Not accurate; based on two decade old data (requires monitors in these orbits to obtain data)
- LONG-TERM HIGH ENERGY DATA FOR ELECTRONS AND PROTONS IN MAGNETOSHERE!!!!!!

Monitors & Ways to Address Needs

- Include monitors on missions in orbits where data is lacking
- Develop a sustained program to measure high energy particles
- Increase awareness in science community for engineering needs
- SEE Program provides advocacy for high energy particle models
- ***More collaboration with non-NASA agencies***

Environment Data & Spacecraft Charging

- Spacecraft charging models presently in use:
  - NASCAP/GEO (NASA Charging Analyzer Program/Geosynchronous Orbit) 3-D
  - NASCAP/LEO - High voltage solar array interactions with the ionosphere, 3-D
  - Tiger (Sandia National Lab) and other Monte Carlo high energy particle deposition codes 3-D
  - Various proprietary deep dielectric charging models
  - Some proprietary 1-D surface charging models (TRW)

On-going Efforts

United States

- SEE Interactive Spacecraft Charging Handbook (NASA/SEE)
  - Surface charging (GEO & polar) & deep dielectric charging
  - Spacecraft charging design guidelines
  - Simple environment models (Maxwellians, AE8, Fontheim)
  - Surface charging models including 3-D effects
  - 1-D deep dielectric charging model (planar & coaxial geometries)

- NASCAP-2K (NASA/SEE & AFRL)
  - 3-D Plasma interactions in GEO, LEO, and Polar orbits
  - Detailed satellite geometry
  - Fontheim auroral environment fit (Maxwellian, power law, and Gaussian)

On-going Efforts (con't)

International

- EQUIPOT
  - Single material surface charging (DERA, part of SPENVIS)
- SOLARC
  - Solar array charging in LEO (ESA, part of SPENVIS)
- DICTAT
  - 1-D deep dielectric charging model (DERA, part of SPENVIS)

Gaps in Data

- Particle spectra for on-orbit anomaly investigations given a time and satellite location (there is data on the net, but not a complete set)
- Accurate enough spectral information for reliable spacecraft charging calculations
- Accurate dynamic models of both
  - Magnetospheric particle spectra (surface charging)
  - Radiation belt electrons (deep dielectric charging)

Monitors Needed

- Particle spectra (1 KeV - 1 MeV) for MEO, GTO, and Molnya orbits
- Data to support Spacecraft Charging Forecasting (see Figure)

Spacecraft Weather + Spacecraft Charging

  - Requires accurate dynamic models of the environment, e.g. advanced versions of
    - MSFM (Magnetospheric Specification & Forecast Model) (Rice University)
    - SALAMMBO (Radiation belts) (ONERA, CNES)
  - Flight & ground data is used as boundary conditions to drive the models
    - Solar wind particle fluxes, polar cap electric fields, etc.
    - Real time data for forecasting & historical data for investigations
    - Automated system for data availability
- Web based availability of all data for use in private by spacecraft manufacturers and operators (Spacecraft charging anomalies have cost $M's over the past few years)

Spacecraft Charging Forecasting:
Spacecraft Weather Coupled with Spacecraft Charging

Environment Data
(satellite & ground)

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Dynamic Models of Magnetospere
& Radiation Belts

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Spacecraft Charging Models

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S/C Charging Forecasts & “Postdictions”

Introductory Comments to Thermospheric Density Needs

- Only empirical or semi-empirical models are addressed
  - Physics-based models provide no additional accuracy when applied to drag estimation
  - Computational overhead of physics-based models is not justified given the lack of accuracy improvement
- The list of suggested measurements is not necessarily exhaustive and should be regarded as a starting point only

Existing Thermospheric Density Models

- Jacchia 1970 (J70)
  - First model to reach 15% accuracy level for total density (current state-of-the-art)
  - Operational use by Air Force Space Command and others
- Marshall Engineering Thermosphere - 1999 Version (MET-99)
  - Total neutral density accuracy of 15%
  - Based upon J70 with seasonal-latitudinal variations from Jacchia 1971
  - Used by NASA and others for spacecraft design and operations
  - MET is the baseline thermosphere model for ISS and the Space Shuttle
- Mass Spectrometer Incoherent Scatter (MSIS)
  - Used by science community for accurate species concentrations
  - Used by NASA for atomic oxygen (AO) estimates
  - Operational use by Navy

Current Thermospheric Modeling Activities

- Density Calibration Technique
  - Observed drag for calibration satellite used to correct model estimates for other spacecraft
  - Short-term (≤ 2 weeks) accuracy of 5% - 7% achieved
  - Studies of correlations with solar and geomagnetic variations in progress
- Fidelity of Thermospheric Model Inputs
  - Comparison of accuracies of various future estimation techniques for solar activity
  - Comparison of accuracies of various future estimation techniques for geomagnetic activity
- Parameterization of operational solar EUV data to replace solar activity indices
  - How well can it be made to perform?
  - What are the associated problems?

Thermospheric Density Gaps

- Model Accuracy at High Latitudes
  - Largest errors occur at latitudes > 50 degrees
  - Joule heating algorithms need improvement
  - High latitude wind effects
  - Electrodynamic drag
  - Other error sources

- E-region and F1-region Model Accuracy
  - Important for de-orbit analyses and planning
  - Boundary conditions at the mesopause
  - Accuracy of total density and species concentration knowledge
  - Transport processes
  - Photochemical effects

Thermospheric Density Gaps (con't)

- Future Estimation of Solar and Geomagnetic Activity
  - Largest source of uncertainty in estimating future values of thermospheric density
  - Currently no useful physics-based model for solar activity
  - Current statistical models require a smoothing kernel larger than the averaging period for smoothed F10.7 used in thermospheric models
  - Techniques for estimating future geomagnetic activity not well developed

- Drag Coefficient Accuracy
  - Altitude variability
  - Gas-surface interactions under thermospheric conditions

Measurements Needed

- Model Accuracy at High Latitudes
  - Drag acceleration
  - Constituent concentrations
  - Temperature
  - Flux and energy of precipitating charged particles
  - Cross-track acceleration
  - Net spacecraft charge
  - Sampling in at least three sun-synchronous orbit planes
- E-region and F1-region Model Accuracy
  - In-track and cross-track accelerations
  - Constituent concentrations
  - Temperature
  - Altitude sampling to as near the mesopause as possible

Measurements Needed (con't)

- Future Estimation of Solar and Geomagnetic Activity
  - Simultaneous solar EUV, MgII, and $F_{10.7}$ data
  - Geomagnetic field as a function of time and magnetic latitude and longitude
  - Solar wind flux and velocity vector
  - Interplanetary magnetic field vector
  - Solar magnetic field as a function of time
  - The acquired data set should extend over multiple solar cycles
- Drag Coefficient Accuracy
  - Drag acceleration
  - Spacecraft velocity, attitude, and mass
  - Thermospheric density and temperature
  - Species concentrations
  - Accommodation coefficient